The Disk Wind in the Young Binaries and the Origin of the Cyclic Activity of Young Stars

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Abstract

We present results of numerical modeling of the cyclic brightness modulation in the young binary systems with the eccentric orbits and low-mass secondary components. It is suggested that the system components accrete the matter from the remnant of the protostellar cloud and, according to the current models, the low-mass companion is the main accretor. Brightness variations of the primary is due to the periodical extinction variations on the line-of-sight caused by the disk wind of the secondary and a common envelope it produces. A matter distribution in the envelope has been calculated in the ballistic approach.

When calculating the optical effects due to the dust component of the disk wind, we adopt the dust to gas mass ratio 1:100 as in the interstellar medium and the optical parameters of the circumstellar dust typical for the young stars. Calculations showed that in the young binaries with the elliptic orbits theoretical light curves demonstrated the more variety of shapes comparing with the case of the circular orbits. In this case parameters of the photometric minima (their depth, duration and the shape of light curves) depend not only on the disk wind parameters and an inclination of the binary orbit to the line-of-sight but also on the longitude of the periastron. A modulation of the scattered radiation of the common envelope with a phase of the orbital period has been investigated in the single scattering approach. It is shown that an amplitude of the modulation is maximal when the system is seen edge-on and has also a non-zero value in the binaries observed pole-on. Possible applications of the theory to the young stellar objects are discussed. In particular, an attention is payed to a resemblance of the light curves in some models with light curves of the objects suspected as candidates to FUORs.

1 Introduction

Photometric observations of the last years show that among young stars one can find the eclipsing systems with a rather long lasting eclipses. For example, in the binary system GW Ori (P = 242^d, Mathieu et al. 1991) where the primary is a T Tauri star (TTS), a duration of the eclipses is about 1/10 of the period (Shevchenko et al. 1998). The duration of the eclipses of the weak T Tauri star (WTTS) KH 15D (P = 48.36^d, Kearns and Herbst 1998; Hamilton et al. 2001; Herbst et al. 2002) is even more: one third of the period. In the binary HD 200775, whose period is about of 3 years (Pogodin et al. 2004) and where the main component is the Herbig Ae/Be star, the duration of the eclipses is comparable with the orbital period (Ismailov 2003). Not long ago one more WTTS H 187 with the eclipse of 3.6 years has been discovered in the young cluster IC 348 (Cohen et al. 2003). To date only one eclipse has been observed completely. Therefore, the period of this system is estimated rather approximately and according to Cohen et al. is about of 4 years. An interpretation of such eclipses by classical models developed for the eclipsing binaries, where either the secondary itself or the gas and dust envelope filling in its Roshe lobe is "an obscuring body", leads to the serious contradictions with the physics of the young stars; in some cases such an interpretation is impossible in principle as in the case of KH 15D and H 187, since during such long lasting eclipses the gas and dust envelope around the secondary must have sizes comparable with the radius of the orbit. Such envelopes are unstable and are quickly to destroy due to the tidal perturbations.

Recently it was shown (Grinin and Tambovtseva 2002 (Paper I)) that in the young binaries which still continue to accrete the matter from the remnants of the protostellar cloud, a rather unusual mechanism of eclipses can occur where the role of "the obscuring body" belongs to the disk wind of the secondary component, namely, to its dusty component. Because of an extended structure of the disk wind, the eclipses evoked by it can be very prolonged. Unlike the classical models of the eclipsing binaries, where the eclipses occur only when the line-of-sight lies in the orbit plane or deviates from the latter at a small angle, the eclipses by the disk wind are possible even at the large inclination angles. The more the inclination angle the longer can be the eclipses. This allows us to suppose that a number of the eclipsing binaries among the young pairs has to be i) larger in comparison with the binaries of the Main Sequence, and ii) the number of the eclipsing systems with the long eclipses has to be larger among the young pairs.

In connection with this, it is interesting to continue a study of the optical effects caused by the disk wind in the young binaries. In the present paper which is continuation of the Paper I we give the results of the numerical simulation of the cyclic phenomena due to the disk wind of the low mass secondary during its motion on the orbit. We investigate a dependence of the theoretical light curves on the disk wind parameters as well as parameters of the binary including its orientation in the space. Unlike Paper I where a solution of such a problem has been obtained for the systems with the circular orbits, here we consider a common case of the binaries with the elliptic orbits.

2 The problem

As in Paper I, we assume the model of the young binary proposed by Artymowizc and Lubow (1996) (AL96) as the basic one, and restrict ourselves to the case when the mass of the secondary companion is much less than that of the primary[1]. In the center of such a system a cavity almost free of the matter is formed under the effect of the periodic gravitational perturbation (Fig. 1). Its typical size depends on the eccentricity e and the mass ratio of the components $q = m_2/m_1$ and is approximately equal to $(2-3) \cdot a$ where a is a large semi-axis of the orbit of the secondary (Artymowizc and Lubow 1994).

The components of the binary accrete the matter from the remnants of the protostellar cloud which forms so-called circumbinary (CB) disk. In this case , the accretion rate onto the low mass component can substantially exceed the accretion rate onto the primary(Artymowizc and Lubow 1994, Bate and Bonnel 1997; Rozyczka and Laughlin 1997). Since the process of the disk accretion is accompanied with the matter outflow from the accretion disk (the disk wind) then at such conditions, the low mass companion becomes a powerful source of the matter which it ejects up (and down) the CB disk plane during its motion along the orbit. Calculations showed that the dust presented in the wind[2] can originate the long lasting eclipses of the primary (Paper I) and could be (at the certain conditions) the source of the thermal radiation whose luminosity in the near infrared region of the spectrum can be comparable with that of the CB disk itself (Grinin 2002).

2.1 A structure of the CB-disk

As an example, a structure of the CB-disk of the young binary with the low mass component is shown on Fig. 1. We calculated the matter distribution in the disk in the hydrodynamical approach by SPH (smoothed particle hydrodynamics) method using a scheme close to that described by Hernquist and Katz (1989) but with a constant smoothing length of the hydrodynamical parameters. In the projection on the sky plane one can see two streams of the matter from the CB disk feeding the accretion disks around the components of the system. In the CB disk itself the wave densities caused by the periodical gravitational perturbations are seen. Such a matter distribution in the CB disk agrees well with results obtained by AL96.

A special feature of the binaries with the elliptic orbits is a global asymmetry in the azimuthal distribution of the CB disk matter that is clearly seen both pole-on and edge-on as well as in the cross-section (Fig. 1). As it was shown by Artymowizc and Lubow (2000), the asymmetric CB disk precesses slowly with a precession period significantly exceeding the orbital one. In the cross-section (Fig. 1, middle panel) CB disk resembles a classical accretion disk around a single young star in which a main part of the matter is concentrated in the geometrically thin equatorial layer with a thickness $H \ll r$.

One of the manifestation of the CB disk global asymmetry mentioned above is a dependence of its geometrical thickness H not only on the distance from the center r but also on the azimuth. For this reason, the precession of the CB disk has to originate a long lasting periodical variations of the extinction in the young binaries observed nearly edge-on when the line-of-sight is tangent to "the surface" of the disk. It is also obviously, that the global

[1] According to the statistics of the Main-Sequence binaries (Duquennoy and Mayor 1991; Mazeh et al. 2000) such mass component ratios are typical for the systems with periods $P \geq 3$ yrs but they can be also found in the systems with shorter periods. In particular, it could be systems with the substellar companions whose number rapidly grows owing to the continuing research programmes (Mayor and Urdy 2000).

[2] As Safier (1993) showed, due to collisions of the dust particles with gas atoms in the accretion disk, the former are carried away by the latter and are present approximately in the same proportion in the disk wind.

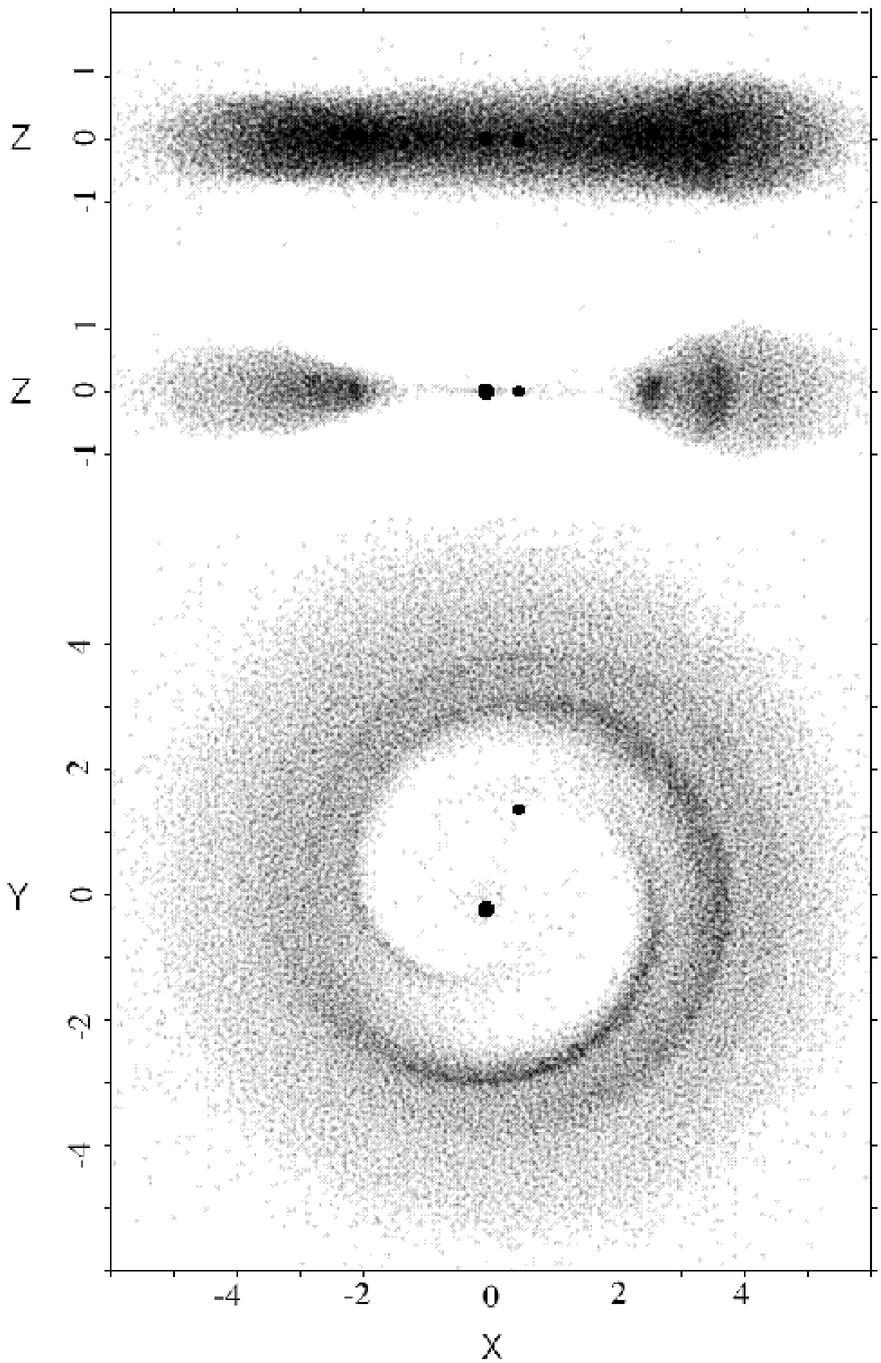

Figure 1: A matter distribution in the CB-disk of the young binary obtained with SPH-method; the view "edge-on" in the projection on XZ plane (the upper panel), the cross-section of the CB-disk in the same plane (the middle panel) and the view "pole-on" (the bottom). The co-ordinates X, Y, Z are expressed in the units of the large semi-axis of the secondary's orbit. The model parameters are $e = 0.5$, mass ratio $q = 0.22$

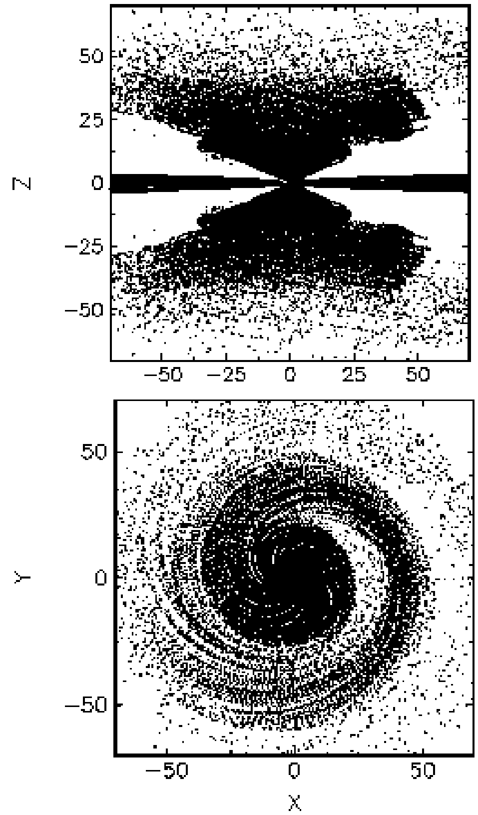

Figure 2: The matter distribution in the common envelope of the young binary created by the disk wind of the secondary in the projection on the XZ-plane (top) and on the equatorial (XY) plane (bottom). The secondary is at the point with the coordinates $X = 1, Y = 0$. The coordinates of the primary in the XY-plane are equal to (0,0). All coordinates are expresses in the units of the large semi-axis of the secondary's orbit. The model parameters are $V_w = 3, U_w = 0.5, e = 0.5$ (see Section 3.2)
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asymmetry of the CB disk is one of the sources of the intrinsic polarization of the young binaries.

3 Formation of the common envelope

The disk wind of the secondary essentially modifies the model of the young binary: during the orbital motion of the secondary it creates a rather complex in its structure asymmetric common envelope (Fig. 2) which partially dissipates in the surrounding space but partially can be captured by the main component. As a result, a dust appears above (and under) the binary system's plane giving an additional extinction on the line-of-sight.

3.1 Inertial properties of the accretion disks

A special feature of the binaries with the elliptic orbits is that the accretion rate onto the system components undergone a strong modulation with a period equaled to the orbital one (AL96). Moreover, in the binaries with elongated orbits ($e \geq 0.3$) a modulation amplitude can be so large that the accretion rate in the apastron and in the periastron can differ by ten and more times (AL96; Rozyczka and Laughflin 1997). The dependence of the accretion rate $\dot{M}_a$ on the orbital period phase can lead to that the mass loss rate in the disk wind $\dot{M}_w$ can be also a periodic function of time. Nevertheless, due to an inertia of the accretion disk, the modulation amplitude of $\dot{M}_w$ depends on the ratio between the orbital period P and the hydrodynamical time t_g. The latter is a characteristic time of the accretion disk dissipation without any feeding. If it is less compared to the orbital period P then the accretion disk has a time to react to the changes on its outer boundary caused by the changes in the accretion rate. In this case $\dot{M}_w \propto \dot{M}_a$. In the opposite case, a reaction of the disk to the changes of $\dot{M}_a$ can be strongly smoothed.

According to Shakura and Sunyaev (1973)

$$t_g = R^2/\nu \tag{1}$$

Here R is the outer radius of the accretion disk, ν is a coefficient of the turbulent viscosity: $\nu = \alpha\, v_s\, H$, where H is a geometrical thickness of the disk, v_s is a sound speed and α is a dimensionless parameter depending on the mechanism of the generation of turbulence in the accretion disk. Taking into account that $v_s/v_\phi \approx H/R$ where v_ϕ is a Keplerian velocity on the outer boundary of the disk and expressing t_g in the units of the orbital period we obtain

$$t_g = (2\pi\alpha)^{-1}(R/H)^2(t_{rot}/P)\,, \tag{2}$$

where t_{rot} is a Keplerian period at the outer boundary of the disk of the low mass companion.

The expression (1) one can rewrite in the form

$$t_g = (2\pi\alpha)^{-1}(R/H)^2 q^{-1/2}(R/a)^{3/2} \tag{3}$$

where a is the large semi-axis of the secondary, $q = m_2/m_1$ is the mass ratio of the components.

According to Artymowizc and Lubow (1994), if the mass ratio $q \approx 0.1$ the outer radius of the secondary accretion disk $R \approx 0.1\, a$. Assuming a "standard" relation for the accretion disks $H\,/R = 0.05$ and $R = 0.1\, a$, we obtain from Eq. (3) $t_g \approx 6.5\, \alpha^{-1}$.

In the modern models (see the review by Stone et al. 2000 and the references therein) the values of α are ranging from 0.005 to 0.5. Assuming the value $\alpha = 0.5$ to estimate the lower limit of t_g, we obtain $t_g \geq 13$.

Hence it follows, that even in the models with the high efficiency of the angular momentum transfer a typical hydrodynamical time of the accretion disk substantially exceeds the orbital period. From this one can conclude that the disk wind forming mainly in the central part of the disk is in no time "to feel" the changes of the accretion rate at its outer boundary. However, observations of the young binaries with the eccentric orbits testifies (see e.g. Pogodin et al. 2004) that there is a modulation of some parameters of the emission line H_α with the phase of the orbital period such as an equivalent width of the line and parameters of its profile. This means, that physical conditions in the central part of the accretion disk where this line is formed undergone the periodical variations connected with the orbital motion of the system components. This variations can be caused by the tidal perturbations and spiral shock waves forming in the accretion disks of the binaries (Sawada

et al. 1986a,b; Bisikalo et al. 1995; Makita et al. 2000). As a result, the disk wind can be strengthened near the orbit periastron. Therefore, further together with the conservative model where $\dot{M}_w = const$, we also consider the model of the binary where the disk wind is strengthening when the system components are approaching each other. For simplicity we investigated the case when the mass loss rate is proportional to the accretion rate.

3.2 Parameters of the disk wind

We remind briefly the main characteristics of the disk winds in the young stars. The numerical modeling by Goodson et al. (1999) shows that the bulk of the matter (up to 80%) is concentrated in the low velocity component of the wind and ejected from the accretion disk in the angle range $\omega \approx 40^\circ - 60^\circ$ where ω is the angle between the vector of the radial velocity of the wind and the symmetry axis of the disk. Near the accretion disk, the disk matter has not only the radial velocity component V_w but also the azimuthal one U_w. At the large distances from the accretion disk the latter decreases due to the angular momentum conservation law and the radial velocity becomes the dominant component. Further, putting the kinematic wind parameters, we shall mean the velocity components V_w and U_w as those which the wind fragments have after completing the acceleration phase when the wind motion occurs inertly. Hartigan et al. (1995) and Hirth et al. (1997) estimated a typical low velocity component of the wind from the observations of the forbidden lines in the spectra of TTSs: few tens kilometers per second at the distances ≥ 1 AU.

Taking into account all mentioned above, we assume that all wind particles are ejected with the same radial velocities V_w isotropically in the angle range $40^\circ \leq \omega \leq 60^\circ$. It is supposed that the disk wind possesses a mirror symmetry relatively to the orbit plane. Since the radius of the accretion disk of the secondary is less compared to the large semi-axis then, for simplification of calculations we adopt that the matter outflows from the point source whose coordinates coincide with those of the secondary, and the mass center of the system coincides with the primary location. The disk wind of the primary was not taking into consideration when modeling because the accretion rate onto this component is much less than that onto the secondary according to the problem condition.

It is also suggested that in the coordinate system of the secondary the disk wind has an axial symmetry. This condition is fulfilled in those cases when one can neglect the tidal perturbations due to the main companion. Since the radius of the accretion disk of the secondary is less compared to the radius of the tidal interaction and the main contribution to the disk wind is given by the internal layers of the accretion disk, such a suggestion seems quite reasonable. An exclusion are binaries with a very large eccentricity. In such systems the outer radius of the secondary accretion disk at the orbit periastron can turn out less than the radius of the tidal interaction; as a result, the part of the matter from this disk can be captured by the primary at the moment of the maximal approach. At these conditions one can expect strong deviations from the azimuthal symmetry in the disk wind.

4 Method of calculation

As in Paper I we suppose that the disk wind consists of the weakly interacting fragments which are treated as independent (probe) particles. When going to the coordinate system of the primary the velocity vector of the particle $\mathbf{V}_w + \mathbf{U}_w$ is summed with the velocity vector of the secondary orbital motion $\mathbf{V}_k$. As a result the disk wind becomes anisotropic:

$$\mathbf{V}_0 = \mathbf{V}_w + \mathbf{U}_w + \mathbf{V}_k. \tag{4}$$

In this case the part of the matter (ejected in the directions opposite to that of the orbital motion of the secondary) can get the velocity less than the escape one and can be captured by the main component.

The calculation of the trajectories of the particles motion in the gravitational field of the primary[3] was carried out in the ballistic approach. The particle velocity $\mathbf{V_0}$ determined by Eq. (4) and its coordinates at the moment of ejection are put as initial conditions in calculation of its trajectory. In the computing process an orbit of the secondary was divided by n fragments in such a way that its motion along each part of the orbit took the same time $\Delta t = P/n$. We put $n = 72$ or 180 (that in the case of the circular orbit corresponded to the orbit step equal to 5° or 2° correspondingly). The same algorithm of the common envelope modeling as in Paper I has been used. Model simulations of the disk wind was carried out via ejection of the probe particles on each step isotropically within the range of solid angles mentioned above into the upper and lower semi-space.

Thus, the model parameters of the problem are:

- an eccentricity of the orbit e; for model simulations it is adopted $e = 0.5$;
- the radial V_w and azimuthal U_w velocity components of the disk wind of the secondary (the Keplerian velocity of the secondary in the periastron is assumed to be equal to the unity: $V_k = 1$);
- the mass loss rate from the accretion disk of the secondary $\dot{M}_w$.

In calculations of the optical characteristics of the dust component in the disk wind we adopted the same dust to gas ratio as in the interstellar medium 1:100. For simplicity we consider a mono-dispersed graphite and silicate mixture of the dust particles whose chemical composition is analogous to that in the interstellar medium (Mathis et al. 1977). We used so-called astrosilicate in our calculations. The radius of the particles $s = 0.1\mu$m, the average density is equal to 3 g cm^{-3}. The optical characteristics of such particles were calculated with the Mie theory in Paper I.

5 Results

We calculated a series of the common envelope models for the different phases of the orbital period with the help of the method described above. As an example, one of them is presented in Fig. 2. In the binaries with the elliptic orbits a concentration of the particles on the line-of-sight in the direction towards the primary (hereafter we shall call this parameter as a column density of the probe particles N) depends not only on the phase of the orbital period ϕ and an inclination of the orbit plane to the line-of-sight θ but also on an orientation of the orbit relatively to an observer. Fig 3. shows four variants of the orientation of the secondary's orbit relatively to the observer for which the column densities N were calculated as a function of ϕ as well as corresponded optical depths τ. A transition from N to the column density of the real particles N_d was fulfilled using re-scaling when the ratio of the total number of the dust particles ejected by the wind over one revolution to the corresponded number of the probe particles was taking into consideration (see Paper I for details). Also we took into account a difference in the cross-sections of the columns: the column density of the probe particles was calculated per the section σ (see below), while that of the dust grains N_d was normalized to the cross-section of 1 cm^2.

[3]Masses of the circumstellar (CS) disks of the young stars usually do not exceed 0.1 $M_\odot$ (see, e.g. Natta et al. 2000) and their self-gravity can be neglected.

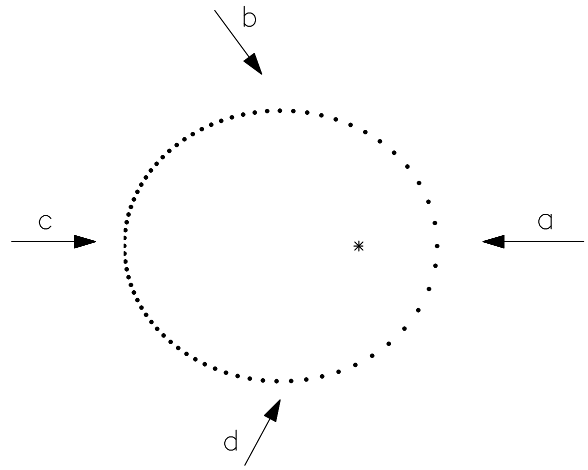

Figure 3: The orbit of the low mass secondary companion of the binary with an eccentricity $e = 0.5$. Arrows point out the four different directions to the observer for which the phase dependence of the column density in Fig. 4 and the light curves in Figs. 5-7 have been calculated.

As an example, Fig. 4 demonstrates a dependence of N on ϕ for one of the model considered. The integer values of the phase correspond to the moments when the secondary passes the periastron. Calculations were made for the different angles of the inclination of the orbit plane θ and the different orientations of the orbit relatively to the observer. The cross-section of the column σ was adopted to be equal to $0.1\,a$ x $0.2\,a$, where a is the large semi-axis of the secondary's orbit. The test calculations showed that for less values of σ the statistic fluctuations increased because of the low number of the probe particles in the column while for larger values of σ smoothing of the details on the light curves took place.

5.1 Amplitudes and shapes of the light curves

As in Paper I, when calculating a dilution of the light of the binary due to the variations of the extinction on the line-of-sight, we adopted that the main source of the radiation was the main component which was treated as a point source. The radiation flux from it decreases when going through the dust component of the disk wind by $e^{-\tau}$ times. When $\tau \gg 1$, that means a strong dilution of the direct radiation of the primary, the radiation flux is determined by the scattered radiation of the CS dust included that of the CS and CB disks as well as the common envelope. Taking this into account we can write

$$F_{obs} = \frac{L_*}{4\pi D^2}\, e^{-\tau} + F_{sc}\,, \qquad (5)$$

where D is a distance from the observer.

As a rule, a scattered light gives only a weak deposit to the direct radiation of the young star and its main function is to restrict the amplitude of the minima in those cases when the direct radiation of the star is strongly diluted due to the absorbtion in the CS medium. Such limiting functions of the scattered radiation of the CS disks of the young stars are the well known phenomenon in the case of UX Ori type stars whose brightness undergoes strong decreases due to the variable CS extinction (Grinin 1988).

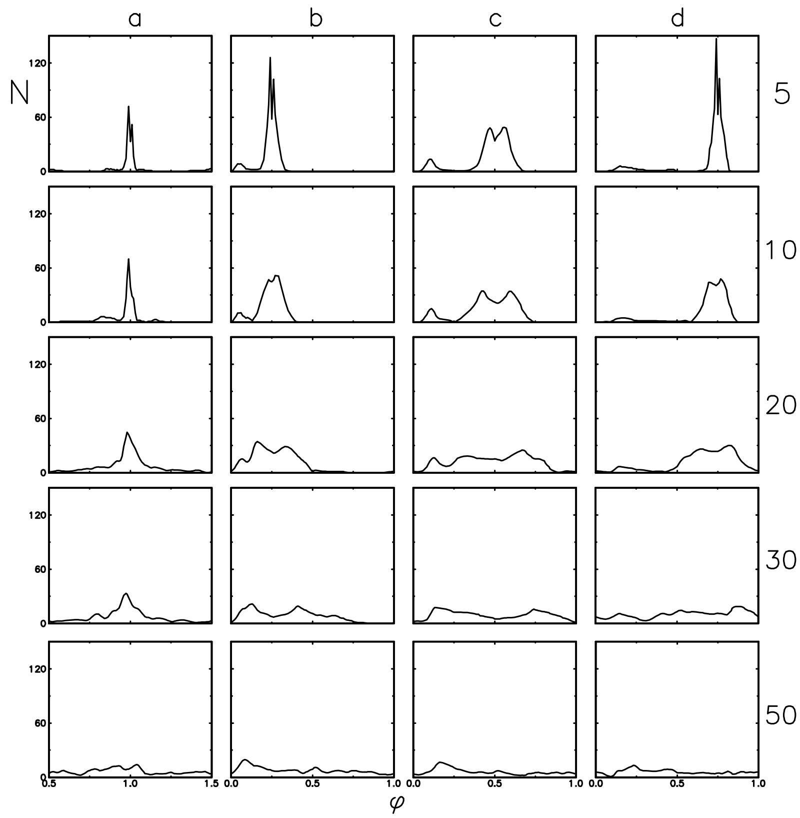

Figure 4: A dependence of the column density of the probe particles N on the phase of the orbital period ϕ in the model with $V_w = 1, U_w = 0, e = 0.5$ for four orientations of the binary system relatively to the observer. The angle θ between the line-of-sight and the equatorial plane of the system is given on the right side.

In Figs. 5-7 a series of the light curves calculated for the different models is presented. For simplicity it is adopted that the flux of the scattered radiation does not depend on the phase of the orbital period and is equal to $0.1\,F_*$. Calculations are made for the wavelength 5500Å centered to the V-band.

Like in the models with the circular orbits (Paper I), the light curves in Figs. 5-7 have an asymmetric two-component shape caused by a conic structure of the disk wind. At some system orientations the two-component shape of the minima is not revealed due to the low resolution because of the column cross-section σ adopted in calculation of $N(\phi)$. Since the stellar disk of the main companion has finite sizes, a similar smoothing of the light curves can also occur in the real situations.

One sees from Figs. 5-7 that at the same other conditions, the longest minima take place in the systems whose eclipses are happened at the moment of passing the apastron by the secondary, and to the contrary, the shortest eclipses has to be observed from the side of the periastron. It is easy to show that a ratio of the eclipse durations at these opposite orientations of the binary is

$$\Delta t_a/\Delta t_p = (1+e)/(1-e)\,. \tag{6}$$

Hence it follows, that when $e = 0.5$ durations of eclipses differ by 3 times.

In the most models considered at the orbit orientation b (Fig. 3) (when an eclipse occurs after a passage of the periastron), the light curve is characterized by the steep descent and a slow ascent while in the same models but in the position d (when an eclipse occurs before a passage of the periastron) the result is the opposite: a decrease of the brightness is slower compared to its increase.

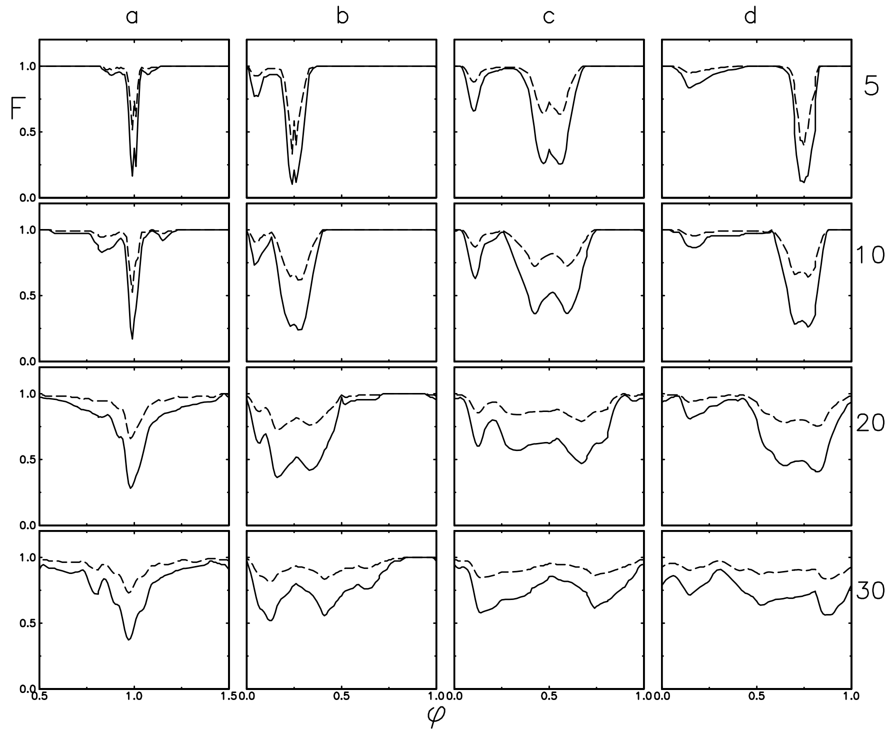

Figure 5: Theoretical light curves of the main system component for the orbit orientations shown in Fig. 3. Model parameters are $e = 0.5, V_w = 1, U_w = 0$, the mass loss rate of the disk wind of the secondary $\dot{M}_w = 10^{-8} M_\odot$ yr^{-1} (solid line) and $3 \cdot 10^{-9} M_\odot$ yr^{-1} (dashed line). The angle θ between the line-of-sight and the plane of the double system is given on the right side.

At the small inclination angles of the orbit a duration of the eclipses is less compared to the period of the orbital motion. An exception are the systems oriented with the apastron to the observer (the variant c in Figs. 5-7): in such cases, even under a small θ an eclipse can last for a rather long time. With increase of the orbit inclination a duration of the eclipses increases and for $\theta \geq 30°$ can be compared with the system period.

As it is seen from Fig. 5, in the models with the low velocities of the disk wind one can see a weaker minimum preceding the main one. A similar feature is also present in the models with circular orbits. As shown in Paper I, its origin is caused by the wind particles ejected during the previous passage of the secondary component on the orbit and captured by the main component. In the models with the high mass loss rate ($\dot{M}_w \geq 10^{-7} M_\odot$ yr^{-1}) and the large inclination angles of the orbit a boundary between the main minimum and its predecessor vanishes resulting the more extended two-component structure of the minima. In the models with larger wind velocity (Fig. 6) a portion of the matter captured by the primary decreases resulting only one main minimum on the light curves.

Calculations show that taking into account a rotation of the disk wind yields a more rapid expansion of the wind in the horizontal directions in comparison with the models where $U_w = 0$. As a result, the depth of the minima decreases but their duration increases (Grinin and Tambovtseva 2003). The minima parameters and their shape depend also on the geometry of the disk wind. Fig. 6 demonstrates results of calculations for two models differing only with open angle of the wind; in one case it is the same as in Fig. 5 ($40 \leq \alpha \leq 60°$), in another case it is 45°. It is seen that in the last case the minima are shorter and have a more symmetric shape.

We remind that all model presented above are calculated in suggestion of a constant mass loss rate. For comparison we also considered the models with a variable mass loss rate: $\dot{M}_w \propto \dot{M}_a$ in which a dependence of $\dot{M}_a$ on ϕ has been taken from AL96. Calculations showed (Fig. 7) that in the models with the variable $\dot{M}_w$ an amplitude of the minima depended on

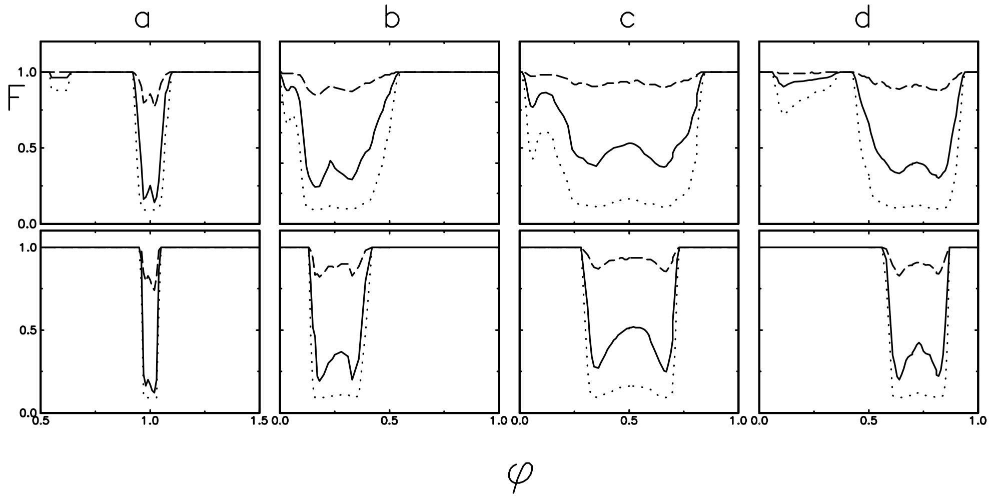

Figure 6: The light curves for the model with parameters: $V_w = 2, U_w = 0, e = 0.5$ with the mass loss rate $\dot{M}_w = 3 \cdot 10^{-9} M_\odot$ yr^{-1} (dashed line), $\dot{M}_w = 3 \cdot 10^{-8} M_\odot$ yr^{-1} (solid line) and $\dot{M}_w = 10^{-7} M_\odot$ yr^{-1} (dots). The angle $\theta = 20°$. Top: $40 \leq \alpha \leq 60°$, bottom: $\alpha = 45°$

the orientation of the orbit of the secondary relatively to the observer that is quite natural: it was maximal in the systems whose periastron was between the observer and the primary (the variant *a* in Fig. 3) and minimal in the case of the opposite orbit orientation (the variant *c* in Fig. 3). As for a shape of the light curves, the difference between these two models is not so essential.

5.2 Modulation of the scattered radiation with the phase of the orbital period

When calculating light curves, we adopted for simplicity that an intensity of the scattered radiation did not depend on the phase of the orbital period. Such a situation is possible if the CB disk is a main source of the scattered radiation. In our case the part of the scattered radiation originates from the disk wind of the secondary and the common envelope created by it, and this part undergoes a periodical modulation. Let us consider a simple example that demonstrates how the phase dependence of the scattered radiation can influence the light curves of the binary.

For this purpose, the intensity of the scattered radiation for two of models considered has been calculated in a single scattering approach. (An analysis showed that this approach was valid for the mayor part of the common envelope at $\dot{M}_w \leq 10^{-8} M_\odot$ per year). The flux of the scattered radiation in this approach is

$$F_{sc} = \frac{L_*}{4\pi D^2}\,\pi s^2\, Q_{sc} \int_V n(\mathbf{r})\, r^{-2}\, f(\gamma)\, e^{-\tau_1 - \tau_2}\, d\mathbf{r} \qquad (7)$$

Here $n(\mathbf{r})$ is a concentration of the particles at the point $\mathbf{r}$, Q_{sc} is a scattering efficiency factor of the dust grain, s is its radius, τ_1 is an optical depth between the point $\mathbf{r}$ and the primary, τ_2 is an optical depth between the point $\mathbf{r}$ and the observer. The integration in Eq. (7) is carried out over all volume V of the common envelope.

As in the previous section, we assume that the dust consists of the mixture with equal amounts of the graphite and astrosilicate particles with the radius $s = 0.1\mu$m. A scattering

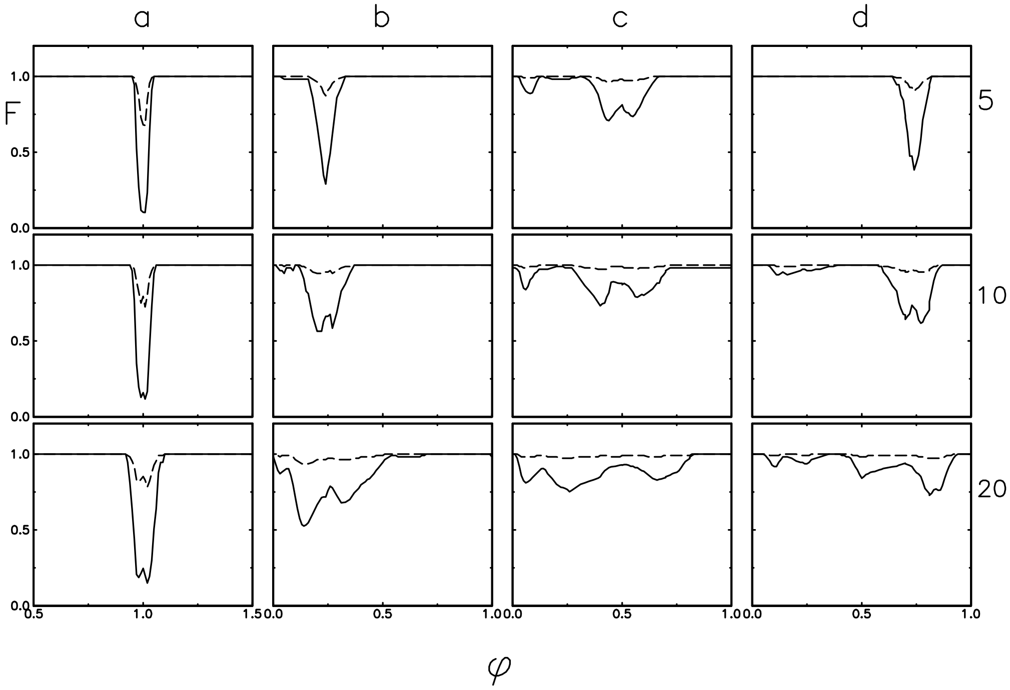

Figure 7: Light curves for the model with a variable mass loss rate ($\dot{M}_w \propto \dot{M}_a$). The solid line corresponds to $\dot{M}_w = 3 \cdot 10^{-8} M_\odot$ yr^{-1} in the periastron and the dashed line to $\dot{M}_w = 3 \cdot 10^{-9} M_\odot$ yr^{-1} in the periastron. The model parameters are $V_w = 2, U_w = 0, e = 0.5$. The angle θ between the line-of-site and the double system plane is given on the right side.

process is described with the Henyey-Greenstein phase function

$$f(\gamma) = \frac{1}{4\,\pi} \frac{1 - g^2}{(1 + g^2 - 2g\ \cos\gamma)^{3/2}} \tag{8}$$

where γ is a scattering angle, the asymmetry factor g is assumed to be equal to 0.5.

Fig. 8a demonstrates the results of calculations for the two system orientations: almost edge-on ($\theta = 5^\circ$) and pole-on. In both cases an integer value of the phase ϕ corresponds to the moment of the periastron passage by the low-mass companion. In the first case the periastron is between the primary and the observer. It is seen that the flux of the scattered radiation F_{sc} reaches its maximum namely in this phase. When observing the system edge-on, this takes place due to the forward elongated scattering phase function. When observing the system pole-on, a maximum of F_{sc} is reached due to that a dilution coefficient weighted over all envelope is maximal at the moment of the periastron passage by the low-mass companion.

One can see from Fig. 8a that a dependence of F_{sc} on the orbital period phase is asymmetric and characterized with a steep growth when the secondary approaches the periastron and a slower decrease when the secondary moves away from it. Calculations show that a degree of asymmetry depends both on the value of the dimensionless velocity of the disk wind V_w and on the eccentricity of the orbit e and its inclination to the line-of-sight. In the model considered above (Fig. 8a) a maximal asymmetry of F_{sc} is reached if the system is observed pole-on.

The functions F_{sc} of ϕ given in Fig. 8a were calculated for the model with $\dot{M}_w = const$. In the models with $\dot{M}_w \propto \dot{M}_a$ a total picture is qualitatively the same. As earlier, a maximum of the scattered radiation is reached in the periastron of the orbit and has even larger amplitude.

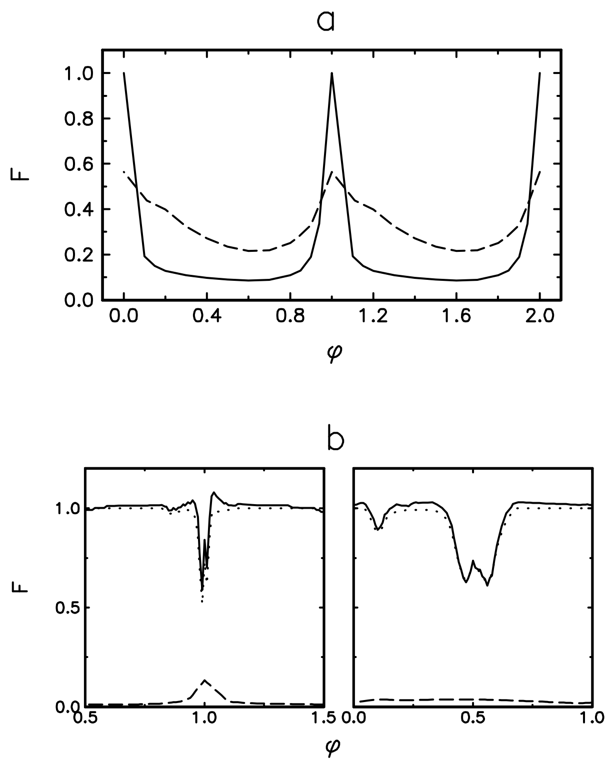

Figure 8: a: An example of the phase dependence of the scattered radiation flux for two system orientations $\theta = 5°$ (solid line) and $\theta = 90°$ (dashed line). The model parameters are $V_w = 1, U_w = 0, e = 0.5$; b: The model of the eclipse of the main companion in the binary system with the account of the phase dependence of the scattered radiation for the same model: in the periastron (left) and apastron (right). The dots indicate to the light curves without the scattered radiation. The dashed line shows a behavior of the scattered light flux with phase.

If to use the values of F_{sc} obtained above in Eq. (5), then asymmetric low-amplitude brightening appears on the light curve on going and/or outgoing the star from the minimum (Fig. 8b). A similar details are observed from time to time on the light curves of some eclipsing young objects (see, e.g. Gürtler et al. 1999; Herbst et al. 2002) and can occur due to scattering the radiation of the primary by those dust particles who have a forward scattering phase function. It is also obviously that taking into account a phase dependence of the scattered light one can expect a brightness increase in the central part of the deep minima whose amplitude is restricted from below to a scattering radiation.

5.3 FUOR-like light curves

As calculations showed, in the models with the large mass loss rate a common envelope formed by the disk wind of the secondary can be so powerful that during a substantial part of the orbital cycle the main component can be obscured from an observer. In such cases the light curve looks like a series of the subsequent flares; the latter, in fact, represents a short time intervals corresponding to the minimal values of the extinction on the line-of-sight (Fig. 9).

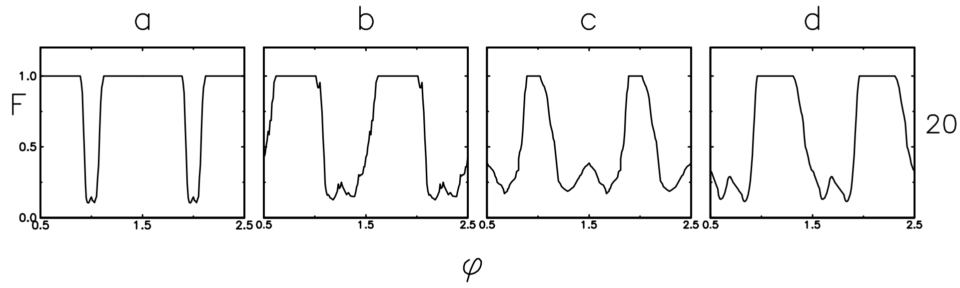

Figure 9: The light curves for the mass loss rate $\dot{M}_w = 10^{-7} M_\odot$ yr^{-1} in the model with parameters $V_w = 3, U_w = 0.5, e = 0.5$ and $\theta = 20°$

This result can be interesting in connection with the debates on the nature of FUORs (see Herbig et al. 2003 and the literature cited there). According to Hartmann and Kenyon (1985) the outbursts of these objects are caused by the repeated "outbursts" of the accretion rate onto the young stars resulting an increase of the luminosity of the accretion disk that is associated with the FUOR flare. According to another hypothesis (Herbig et al. 2003), the FUORs outbursts are caused by the changes in the star luminosity. Both hypotheses are not free of difficulties. Therefore, as an alternation, it is interesting to consider a possibility to interpret the light curves of some FUOR-like objects on the base of the young binary model, in which the primary (a star of a high luminosity) is periodically screened by the gas and dust common envelope formed by the disk wind of the secondary.

6 Discussion

Thus, the theoretical light curves of the young binaries in which the eclipses of the main component are caused by the disk wind of the secondary companion are characterized with a large variety of the shapes, and in many cases absolutely do not resemble the classical light curves observed in the usual eclipsing binaries. If the mass loss rate by the accretion disk of the secondary $\dot{M}_w \geq 3\,10^{-8}$, the eclipses can be observed even if its orbital plane is strongly inclined to the line-of-sight. The duration of such eclipses can be compared with a period of the orbital motion. Taking into consideration this fact as well as a large number of the double and multiple systems among the young stars (see the review by Mathieu et al. 2000), one can expect an existence of the large-scaled cyclic brightness variability in many young stars. Therefore, it is reasonable to suppose, that several young eclipsing systems with the long lasting eclipses discovered not long ago is, in fact, a rather wide-spread population of the young stars whose number will be rapidly increase with an accumulation of the photometric data on the young clusters. We suppose that the UX Ori type stars also belong to such eclipsing systems; the cyclic activity of these stars have been interpreted in assumption of their binarity by Grinin et al. (1998), Rostopchina et al. (1999) and Bertout (2000).

There is one more feature in the model of eclipse considered here which is necessary to take into account for an analysis of the continuous photometric observations of the young stars. As mentioned in Section 2, in the binaries with the eccentric orbits the CB disk is characterized with the global asymmetry and slowly precesses. Observations of such systems under a small inclination to their equatorial plane have to reveal slow (secular) variations of the extinction and, hence, the brightness of the primary. Theoretically a situation is possible, when a direct radiation of the companions will be completely blocked by the CB disk during

some time. In addition, under the effects of the tidal interactions with the CB disk, the orbits of the companions also have to precess slowly. This means, that in the models of eclipses considered a slow transition from the variant of the eclipse a to d (Figs. 5 - 7) has to take place implying slow changes in the parameters of minima: their depth, duration and shape.

Possibly, the exotic eclipsing system KH 15D mentioned in Introduction belongs to such objects; its binarity has been revealed recently by Johnson et al. (2004) on the base of the variations of the radial velocity of the main component and estimated eccentricity (0.68 $\leq e \leq$ 0.80). An analysis of the archive photographic observational data (Johnson and Winn 2004) showed that the brightness of KH 15D was slowly decreasing during the last 40 years (see also Barsunova et al. 2004 on this topic). The duration of eclipses (Herbst et al. 2002) and their depth (Johnson and Winn 2004) were also slowly changing. According to the data of the Harvard collection of the photographic observations the duration of the KH 15D eclipses in the beginning of the last century was essentially less than at the present time (Winn et al. 2003). All these features can be explained with the disk wind eclipse model at the condition that the orbit of the secondary is highly elongated and precesses.

Another possible application of the model considered can be connected with an interpretation of the large scale photomertic activity of some candidates to FUORs. An analysis of the published photometry of such objects as V1515 Cyg (Hartmann et al. 1993) and Z CMa (van den Ancker et al. 2004) shows that their light curves look like the theoretical ones presented in Figs. 5-7. Keeping this in mind and that some FUORs are members of the double systems, one can consider a possibility of the substantial (in amplitudes) variations of their brightness due to the cyclic variations of the extinction on the line-of-sight as reliable and worth of further investigations[4]

As we saw above, a dependence of the scattered radiation on the phase of the orbital cycle can lead to appearance of the fine details on the light curves: a small brightness increase when ongoing and/or outgoing the minimum. More essential, however, the circumstance that the motion of the densest part of the common envelope on the orbit has to evoke a periodical modulation both of the intrinsic polarization of the young binary and its infrared excess. And this modulation can be observed at any orientation of the binary relatively to the observer. This gives a possibility to reveal close binaries whose orbit planes are close to the sky plane and which are hardly discovered for this reason.

At last, it should be noted that one of the assumption made for calculation simplifying was about a negligible influence of the primary disk wind on the common envelope structure. Such an approach was valid in the model of binary considered above since the secondary was the principle accretor and, therefore, the main source of the matter forming the common envelope. However, even at this condition, the role of the primary disk wind can be essential when investigating the cycle activity of the binary at the other wavelengths, and first of all, in the X-ray. Really, as estimates show, a collision of the two disk winds even with rather modest mass loss rates of about of $10^{-9} M_{\odot}$ and the velocity of 100 km/s is equivalent to the energy release of order of $3 \cdot 10^{30}$ erg/s. It is comparable with the X-ray luminosity of many young stars (see the review by Glassgold et al. 2000) and has to be taken into account in interpretation of the X-ray radiation of the young objects.

[4]Note, that Bonnel and Bastien (1992) discussed the role of the FUORs binarity in connection with a possibility of the periodic increase of the accretion rate onto the main companion initiated the flares to their opinion.

7 Conclusion

The results presented above show that the behavior of the optical characteristics of the young binaries with the eccentric orbits strongly depend on that how two main processes are connected: an accretion of the matter from the CB disk onto the system components and a matter outflow from the accretion disks surrounding them. Therefore, one of the clue task in the physics of the young binaries is a self-consistent solution of the problem when both of these processes are tightly connected. In particular, it would be important to investigate the role of the tidal interactions in the formation of the disk winds of the system companions and determine a phase dependence of the mass loss rate from the accretion disk of the secondary component.

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